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ENVIRONMENTALLY ACCEPTABLE DISPOSAL OF WASTES
FROM VEGETABLE PROCESSING INDUSTRIES

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ENVIRONMENTALLY ACCEPTABLE DISPOSAL OF WASTES FROM VEGETABLE PROCESSING INDUSTRIES

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ABSTRACT

The environmental soundness of waste disposal practices is already a major concern of industrialized societies. For wastes with low heavy metals content originating from vegetable processing industries, recycling through intensive silviculture seems to offer an almost ideal solution. Starting from the continuous need of trees for water and nutrients during the growing season, various designs involving optimized supply of trees with their living necessities, can be visualized. However, in order to quickly achieve effectiveness, the intensive silviculture of monoclonal stands of fast growing species appears irreplaceable. Such areas can be irrigated with rates equivalent to daily atmospheric demand for evapotranspiration, thus aiming at a zero percolation rate.

Intensive silviculture combined with fast growing hybrid poplars and willows has been applied for the disposal of effluent resulting from the operation of Cobi Foods in London, Ontario (frozen peas and corn during summer, french fries during winter). This paper provides information about the survival and growth performances of the poplar clones included in the experiment, as well as some results with respect to renovation efficiency of the system. Other design concepts involving fast growing species are discussed together with preliminary criteria for clone selection.

INTRODUCTION

A large number of food production facilities that process vegetables and fruits - canned, frozen, picked or dehydrated - are located in urban areas or near small population centres (Green and Kramer, 1979). As a consequence, waste disposal requirements are tight, with strict emphasis on elimination of odour and ground water contamination. At the same time, the industry produces wastewaters that are highly biodegradable and low to very low in heavy metal content but have considerable seasonal flow variation (composition, strength and flow amount), due to product and processing style. Processing of these wastes poses serious problems and involves significant costs.

Depending on land conditions, possibilities, attitudes and regulations, currently these wastes are subject to primary and secondary treatment while the resultant effluent is land treated by one of the following methods: overland flow, irrigation and infiltration-percolation.

From another viewpoint, the interest in land treatment of wastewaters, mostly of municipal origin, in forested areas, has rapidly grown in the last two decades, albeit not always accompanied by a sufficient integration with already existing hydrogeological, soil and meteorological knowledge. Consequently, a number of projects have sprung up. Generally, designed at an absolute minimum cost, they aim only at fast disposal of large flows over very permeable soils that happen to be under forest vegetation. Such operations, in fact, ignore or do not take full advantage of the true reprocessing ability that a forest ecosystem can accomplish if wastes of the kind produced by the food processing industry are administered to the ecosystem at reasonable rates. An analysis of the multi-faceted "living filter" concept as applied to wastewater renovation has shown that it has considerable potential to be integrated with other elements of disposal technology and site, in a manner that would optimize the reprocessing ability of the forest, natural or plantation.

An opportunity to integrate disposal needs with the recycling potential of a forest plantation was offered by the upgrading of treatment facilities of Cobi Foods (formerly Hardee Farms Ltd.) in London, Ontario, a plant that produced fast frozen peas and corn during summer and french fries from stored potatoes during winter. Encroaching housing developments around the plant have made the previous effluent disposal procedure objectionable, which was irrigation over cornfield, mostly because of odor and wind drift of aerosols. An early report on this plantation was given by Papadopol and Nolan (1985).

BRIEF DESCRIPTION OF TREATMENT SYSTEM

General

The wastewater disposal system in place prior to 1983, based on aerated lagoons and spray irrigation, functioned in a satisfactory manner

as long as the plant operated only during summertime. Inclusion of potato processing has curtailed the winter rest and increased the organic load of wastewater which, in turn, has accentuated the odor problem at the lagoon, settling basin and irrigation area.

To cope with the new situation, several alternatives of aerobic treatment were examined and subsequently rejected because of high capital costs, energy requirements and much increased sludge production. Instead, the following treatment sequence was selected:

- wastewater treatment in an anaerobic reactor
- improved aeration of lagoons
- installation of a secondary clarifier
- replacement of the spray irrigation with an open surface ditch/planted mound system (DMS)

Details of the first three stages, mainly covering the anaerobic reactor that was based on an original design, were given by Love (1985). The last stage became necessary mostly in order to change the way effluent was recycled. Firstly, the wind drift of aerosols inherently resulting from spray irrigation had to be eliminated. Secondly, effluent had to be returned after treatment to lagoons and thereafter discharged in a creek. For this, the effluent that resulted from the anaerobic reactor required considerable "polishing": small suspended solids removal and depletion of soluble solids.

The purpose of the silviculture project - the fourth stage - was to demonstrate and assess the technical and environmental feasibility of effluent polishing as well as to determine the behaviour of forest species in such conditions.

Principles of functioning

In order to achieve enhanced processing of effluent in the DMS, a consumer (plantation) was combined with a set-up (mounds and ditches) that fosters access of organic matter from effluent into the mound and enhances decomposition in the soil.

To achieve almost immediate results with respect to enhanced evapotranspiration and nutrient depletion, some fast growing species, suitable to grow in temperate climates, were chosen. Poplars and willows are known as groups of species that have great transpirational requirements, numerous stomatas, large foliage and high nutritional demands (Barneoud et al. 1982; Dickman and Stuart, 1983). Both these species have been developed by breeders in a large number of hybrids having various traits amongst which, remarkable for our scope, are high rate of growth, conic crowns, dark foliage, large foliar area, immunity to foliar diseases and tolerance to high soil moisture. With respect to this last trait, generally, poplars are known to stand periodic flooding with running water up to 90 days, however, they grow better in a soil environment that has both an aerated layer and unlimited access to moisture. Willows can stand very long inundations with stagnant water, in some cases for over 300 days, a fact that opens the possibility of

building shallow lagoons planted with flood tolerant trees. Also, willows develop a very hairy root system with a good potential for soil erosion control on slopes.

With respect to water requirements, both species are expected to place high demands on soil during the growing season, when their very impressive crown and leaf development result in a rough canopy characterized by a considerably increased evapotranspiration potential (Pruitt et al. 1972; Papadopol, 1984; Pettygrove and Asano, 1985). The crown, more precisely leaves and small branches, are also the organs that require the highest amount of nitrogen, thus having the potential to recycle the nitrogen load of wastewater. Since both evapotranspiration and nutrient depletion depend on foliage development/activity, two elements appear to have considerable importance with respect to establishment of such systems, namely, (1) the plantation is functional only during the growing season, and (2) the health of the foliage is of capital importance.

In nature, soil is the place of sophisticated decomposition processes. While these processes are continuous, their rates are subject to changes in the immediate environment, mostly related to temperature, moisture and aeration. They occur in the vadose or unsaturated zone of the soil. This zone consists of all materials up from and including the capillary fringe to the earth's surface (Reynolds and Elrick, 1986; Canter et al. 1987). In the DMS, an attempt was made to foster decomposition processes by extending the vadose zone. Also, a rate increase of this process was expected to result from: (1) increased exposure of soil to air and water diffusion, and (2) facilitated warming of soil by direct solar radiation, initially, and, subsequently, by air circulation along the ditches.

The functioning of DMS is obviously subject to local weather and soil conditions and changes. Its effectiveness is positively affected, in general, by a long growing season, higher annual temperature, low precipitation amount during the growing season and by a sunny climate. Also, intervals with high winds and invasions of dry air may sharply enhance the consumptive use of DMS. The system has, however, some site limitations in the fact that it cannot be realized with local material on soils that are too permeable, because of percolation risks.

Land organization

An area of about 2 hectares was destined to DMS. It was profiled into 6 mounds and 7 ditches with north-south orientation, and the centres of the mounds spaced 12.5 metres apart. The natural southward slope of about 1.5% was preserved for both mounds and ditches, thus providing for gravitational effluent circulation. However, in order to maintain constant effluent levels as well as to slow the flow, the ditches were divided into four sections by small transversal dykes, equipped with pipe discharges. The drop between these compartments was between 0.3 to 0.5 metres. This configuration provided for 1-1.5 metre mound rise above the effluent level where ditches were full, and approximately 0.8 to 1.3 metres of effluent depth throughout the ditch centres. As a result of planting, the tops of the mounds were flattened.

In the particular case of the Hardee Farms system, the ditch irrigation approach took advantage of the low permeability of the local soil: a clay loam. The presence of a constant effluent level in ditches secured a steady water supply by capillary rise to trees planted on the mounds. In the first years of operation, before the slopes became covered with grass, the capillary fringe was apparent as a zone of dark, moist soil above the effluent level.

Tree plantation

Two rows of poplars spaced 2.4 metres apart and 1.5 metres in length were planted on the top of each mound. Willow was planted on the slopes of mounds, closer to the water table, one row on each side of the mounds. Only willow was planted on these more humid emplacements because of its well-known tolerance for heavy, unaerated soils. The establishment of the plantation was made with unrooted cuttings for both poplars and willows.

Due to the experimental nature of this project, as well as to large variability amongst poplar clones with respect to growth, crown shape and other traits, a number of Populus clones were chosen, namely:

DN-2	P. euramericana cv. 'Baden 431'
DN-5	P. euramericana cv. 'Gelrica'
DN-55	P. deltoides x P. nigra
NM-6	P. nigra x P. maximowiczii

Each poplar clone was planted in 8 replications of 50 trees.

During the growing seasons of 1983 and 1984, the plantation was tended by hoeing in the immediate vicinity of the trees, as well as by spraying the rest of the area with Roundup (10 ml product per litre of water). The use of Roundup for controlling competing vegetation was very effective, the soil remaining almost bare.

In order to determine the growth performance of clones, at the end of the growing seasons of 1983-86, the heights and diameters at breast height were measured integrally. The results were averaged per replication and then made input to analysis of variance in order to compare growth performance of poplar clones. Black willow was not included in this comparison because trees of this species were positioned differently than poplars with respect to the mound, and consequently their access to the water source was eased. Results for black willow are given separately.

In the summer of 1985, tests were conducted to determine influences of the mound system on the effluent. These consisted of flow measurements and C.O.D., NH_3 and P analyses, performed both on effluent that entered and exited the system.

RESULTS

Plantation survival

A check of the survival of the cuttings was done in July 1983. At that stage, the survival was 97, 100, 96, 99 and 93 for the clones DN-2, DN-5, DN-55, NM-6 and black willow, respectively. These initial figures represent a very promising start, particularly if we take in consideration the fact that initially the cuttings did not have access to water held in capillary fringe, as well as the natural trend of a mound to drain actively.

Plantation growth

As already mentioned, the operation of such a plantation is closely related to its development, so that deficits of saturation in the atmosphere would foster unlimited transpiration of large crowns. Consequently, information about the development rhythm of the trees is essential for choosing clones that would accomplish their function at the earliest possible date.

Table 1. Average Dimensions of Trees at the End of Growing Seasons of 1983-1986

Clone/species	No. of trees	1983 average	1984 average	1985 average	1986 average
		Total Height (m)			
DN-2	376	1.19	3.23	4.97	6.56
DN-5	372	1.10	2.73	4.15	5.86
DN-55	379	1.31	3.38	4.98	6.56
NM-6	385	1.32	3.25	4.97	6.60
Exp. F values		1.726	4.270	3.464	2,639
		Diameter at Breast Height (cm)			
DN-2	376	Not	2.48	4.50	6.74
DN-5	372	measured	1.69	3.47	5.63
DN-55	379	in	2.43	4.35	6.75
NM-6	385	1983	2.13	4.06	6.48
Exp. F values			4.233	2.949	3.085

Analysis of data in Table 1 shows impressive development of poplars when planted as part of a DMS. Three of the clones show remarkable dimensional uniformity while clone DN-5 has consistently been the slowest. The differentiation process amongst clones, expressed by experimental F values, appears to have been the greatest in 1984. Parallel examination

of height and diameter data at the end of 1986, combined with previous observations on numerous poplar plantations, show that the allocation of biomass is well balanced and growth processes are active.

The average dimensions of black willow at the end of 1986 were 3.76 m in height and 4.21 cm as diameter at breast height. Due mostly to large available spacing on one side, the black willow is still keeping a shrub habit, trees generally leaning over the ditches. Both by their initial placement in a lower position and by slower growth rhythm as compared to poplar, at this stage the DMS presents one upper story of poplar and a lower story of willow that maintains well the slope of the mound and partially covers the open surface of effluent. At the end of 1986 the plantation consisted of strips of poplar and willow interrupted by corridors that are narrower than the open surface of effluent, thus having a large foliar area exposed to wind. It is presumed that the aerodynamic effect of wind on evapotranspiration of the plantation at this stage is maximum for winds oriented north-south.

Phytosanitary state of plantation

Since the water consumption function of DMS largely depends on the transpiration part of the total system's evapotranspiration, attention was focused on its foliage. The plantation was thoroughly inspected numerous times for potential insect and foliar disease problems. None have been found yet. From general experience with poplar clones, one can appreciate that a plantation is always more resistant to diseases or less damaged by insects when its vigour is high or, conversely, that absence of insect/disease problems is a sure proof of vigour. The case of the plantation in London is only a confirmation of this rule. However, some of these factors may appear later in the life cycle.

Observations about foliage and crown

From the viewpoint of plantation operation, one is interested in the longest possible duration of foliage during one single growing season. This means that thorough, comparative phenological observations are needed in clonal trials in order to select the desired clone. Sporadic observations made on this plantation have shown that clone NM-6 appears to have the longest growing season. It generally maintains its leaves in an obviously active state, until the appearance of the first frost, which causes the leaf fall but leaves the twigs unaffected. The foliage of NM-6 also presents a characteristic dark green colour, which should result in increased absorbtion of solar radiation and thus higher transpirational demand. In contrast with it, clone DN-5 already develops some yellow leaves in August and the leaves are shed well before the first frost, due to an obvious aging effect which leads to separation mostly triggered by stronger winds.

With respect to crown shape and branching pattern, for enhanced transpiration purposes, a large conical crown with dense foliage has perhaps a larger amount of transpiration as compared to a clone with a narrow clone or sparse foliage. Judged on this criteria, clones DN-5 and DN-55 do not appear to be optimally suited for this concept. However, the

assessment should rest ultimately on studies of transpiration intensity and foliage amount.

One last observation refers to behaviour of poplars leaves when subject to small eddies that normally appear in canopy. Due to a characteristic of their petiole, which is flattened, the majority of poplar clones have leaves that flutter at the smallest eddy. However, some of the fast growing clones developed for intensive culture do not have this trait. Perhaps such clones should not be used in DMS because, presumably, their still leaves have less exchanges with the surrounding atmosphere.

Effluent renovation efficiency

As already mentioned, the renovation capacity of DMS rests on two main processes: exhaustion of the water towards the atmosphere in response to a demand that is meteorologically controlled and decomposition of the organic load in the artifically created vadose zone of the mound.

A preliminary assessment performance of the system in terms of both flow reduction and effluent purification is presented in Table 2, that shows removal efficiency of DMS when fed with lagoon effluent and effluent resulting from the anaerobic treatment.

Table 2. Estimated Performance of Tree Plantation.

	Lagoon Effluent			Effluent from Anaerobic Treatment		
Trait	Flow In	Flow Out	Removal Effic. %	Flow In	Flow Out	Removal Effic. %
Flow (gpm)	120	70	41.7	60	35	41.7
C.O.D. (mg/l)	347	239	32.7	2701	1298	51.9
NH3 (mg/l)	37	18	51.4	121	49	59.5
P (mg/l)	11	7	36.6	17	10	41.2

In the first place, it appears that the system has significantly decreased the flow of effluent. Due to rudimentary measurement techniques used, it was not possible to determine the hydrological balance of DMS and to ascertain the ratio of evapotranspiration over infiltration. However, as a result to local soil texture and permanence of water in ditches even when the input flow was reduced, there is reason to believe that deep percolation was low. As a consequence, a flow reduction of over 40%, due mostly to transpiration, appears very impressive and is likely to increase further until complete canopy closure.

Secondly, the reductions of C.O.D. and NH_3, both due mostly to processes in vadose zone and to slow movement of effluent along ditches, are very remarkable. Also, the P reduction, that is normally attributable to the precipitation of phosphate ion with Fe or Al compounds, was also fostered by the prolonged time residence of effluent in ditches.

Thirdly, the renovation efficiency increased when the system was fed with high strength effluent, as compared to lagoon effluent, while the flow reduction - which was dependent mostly on meteorological conditions - remained the same. This finding suggests that, for maximized renovation, the DMS should be operated with a flexible time residence of effluent, with longer residences for higher effluent strengths. Thus, presumably, the system could attain almost complete reduction of C.O.D. and NH_3. Of course, such an operation would require a larger area with DMS.

DISCUSSION

A reprocessing system based on forest vegetation will have its performance influenced by length of growing season, and thus by climate, in any part of the world. In the northern hemisphere, at latitudes of temperate zone and for hardwood species, this means roughly the April-September interval, with the daily atmospheric demand for evaporation closely following the variation of daily average temperature, thus with considerable variation from one day to another. Although the majority of plants that process vegetable farm products have a seasonal operation too, their waste output being variable in time, amount and strength, is unlikely to be matched with the recycling ability of a plantation on a day-to-day basis. Hence a lagoon system, operating as a buffer storage, already existing at almost every facility, will have to continue its role. However, based on the results of this research, it appears that for some facilities with enough land base, this concept can be diversified so as to accomplish multiple functions. On soils that have low infiltration rates, the classic lagoons can be replaced with DMS, dimensioned according to needs, most likely based on the C.O.D. and nitrogen reduction efficiency. The polished effluent coming out of this system can be irrigated by sprinkling on another plantation for consumptive use or on any agricultural crop. However, it would be beneficial for the plant to maintain another hardwood plantation as a place where sludge recycling could take place.

The operation of effluent recycling plantations that are not based on DMS but consist of typical sprinkling irrigation systems under the canopy should be based in the future on the daily atmospheric demand for evaporation, which can be rigorously monitored and administered daily as irrigation rate (Papadopol, 1984). Such an operational criterion would maximize the consumptive use and reduce deep percolation. With careful consideration of local soil factors, this approach may allow for irrigation of effluent in a plantation even on soils having high permeability with, however, no percolation risks. In such a case, though, a lagoon is an absolute necessity, mostly for the buffering effect. The almost complete avoidance of deep percolation of such a system is feasible by fragmenting the daily irrigation rate in numerous "shots". Such an operation would also allow for the highest retrieval of nitrogen via the tree.

Another design possibility is created by the fact that willow trees can stand very long floodings. For small facilities with seasonal

operations, a typical shallow lagoon can be planted with widely spaced willows. Since willow allows for a considerable level variation of the flood, such a lagoon would easily accommodate the peak flows. Willows planted in a shallow lagoon will transpire copiously and would deplete a sizable amount of the nitrogen load of water at the same time. While such a design would have a high degree of acceptance, due to improved landscaping, it has a drawback in the fact that it doesn't offer a possibility for sludge disposal.

Intensive silviculture combined with waste disposal originating from the food processing industry, in systems operated at rates controlled by changes in environment appear to represent an almost ideal blend from the environmental viewpoint. However, this technology isn't by any means confined only to use of poplars and willows. The same concept can work in mature, existing stands with under the canopy irrigation, accomplished by low pressure agricultural sprinklers. It can also work in conifer plantations or natural stands, in this case the seasonal functionality being longer. Also, the concept can be adapted even more successfully to species and evaporative demands existing in other geographic areas.

With respect to functionality, a plantation of fast growing hardwoods will probably always be preferred because of its almost immediate effectiveness, in comparison to, for instance, a slower growing conifer plantation. Also, a new plantation has the advantage of allowing for a designed tree density, matching perfectly a network of sprinklers or a system of mounds. It also can be shaped to fit certain areas of a property, usually the least productive, where only trees can grow, etc.

An important advantage of intensively growing forest plantations as a means of recycling wastes originating in the food processing industry, rests in the potential of plantation to allow land treatment of waste solids or sludges while the crop is growing. Because sludges from secondary treatment are still biologically active and will putrefy, the risk of intolerable odours is great when only simple land treatment is considered. Consequently, handling of such waste requires some form of "containment" which will not restrict the biological activity. Soil incorporation, in fact a form of composting, remains perhaps the most effective way to deal with destruction resistant matter such as tomato and fruit peels. While agricultural crops and grass cannot allow incorporation during the growing season, a properly spaced plantation has implicit provision for the circulation of large discharging vehicles, followed immediately by appropriate tillage. Moreover, disposal of sludges during the growing season, when both water and nutrient requirements of trees are high while soil temperature and aeration are favourable for mineralization, in fact increase substantially the recycling efficiency of a plantation as compared to grass or agricultural crop systems.

Considering the particularities of the effluent resulting from vegetable processing industries (Katsuyama, 1979), if an attempt is made to compare a typical plantation irrigated with amounts equal to atmospheric demand for evapotranspiration with a ditch/mound system, there is reason to believe that the former system is more suitable to deal with huge liquid amounts, while the latter can probably process high strength

effluent more effectively. This last ability appears to result from the enhanced biological activity that occurs in the vadose zone of the artifically created mound. Placing a thirsty consumer (plantation) over an unsaturated zone sitting over a capillary fringe constituted of effluent is likely to foster permanent diffusion of it in the vadose zone. The vadose zone provides excellent conditions for microbial growth and mineralization of dissolved solids while the consumer maintains a suction head that creates an upward flow from the fringe into the unsaturated zone. Concomitantly, the plantation places a high nutritional demand, mainly for nitrogen, on the mound, thus processing it as soon as it is mineralized. The DMS represents also a contained way of processing. While a system based on sprinkling irrigation has a certain proportion of effluent transformed in aerosols that could be a nuisance, if not a health hazard, what the DMS discharges into the atmosphere is only distilled water.

A selection amongst the recycling possibilities enumerated above has to be made on the basis of type of waste, other existing treatment facilities, local soil conditions, climate, special local requirements and cost.

CONCLUSIONS

Tree plantations of fast growing species can be successfully used as recycling areas for the wastewater and sludge resulting from vegetable processing industry. It appears that to this end it is both necessary and effective to create widely spaced plantations able to develop large crowns and to take full advantage of the wind enhancements of evapotranspiration. A typical plantation for effluent recycling can accommodate both daily irrigation with effluent and periodic administration of sludge, followed by incorporation with tillage equipment.

A variant of this recycling technology, based on an open ditch/planted mound system proved also very effective, particularly for high strength effluent. While a considerable part of the flow input to the system has been transpired by the poplar foliage, the conditions inside the mounds have intensified biological activity through existence of an unsaturated zone over a capillary fringe supplied with effluent. As a result, the load of effluent has decreased significantly.

More research is needed in order to increase the effectiveness of this concept even further. While poplar appears to be a reliable candidate for this technology, numerous other species that can tolerate high soil moisture and have high nutritional demands should be investigated. Amongst these, for temperate zone, willow and sycamore are of greatest interest. In screening trees clones for this concept, research should establish ideal clone types (ideotypes). The following traits will most likely increase the consumptive use of water: long duration of foliage, foliage of a dark colour, large crowns, trembling leaves, high foliar nitrogen content and immunity to foliar diseases. Research is also necessary for determining optimized operation of plantation recycling systems (with or without ditch/mound), including

provision for prolonged rainy weather and high soil hydraulic conductivity. Administration of the irrigation rate and distribution of the organic load eventually should be integrated into a complex hardware and software system, operating accordingly on the basis of models for evapotranspiration, decomposition and nitrogen uptake. Specific research should aim at determining the rates of these processes subject to changes in environmental conditions.

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